XII. Polarity and Amplitude of the U Wave of the Electrocardiogram in Relation to that of the T Wave

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Many authorities regard a negative U wave in the electrocardiogram as always abnormal. There has been relatively little clinical application of this concept for several reasons. The U wave is frequently difficult to recognize, its onset and termination are often poorly delineated, and determination of its polarity is sometimes impossible even for the experienced observer. Since the origin of the normal U wave is not clearly understood, it is difficult to attribute the finding of an abnormal U wave to any specific physiologic or pathologic event. It seemed that this problem might be approached by studying the polarity and amplitude of the U wave in relation to other components of the electrocardiogram about which there is more theoretical and practical knowledge.

Methods and Materials

The material consisted of electrocardiograms selected at random from the files of the Division of Cardiology of the Philadelphia General Hospital. In some cases (groups A, B, C, and D), 24 additional unipolar chest and abdominal leads were recorded. These included leads made at levels 1 (V'), 2 (V''), and 3 (V''') intercostal spaces higher than the conventional V-lead level, as well as leads recorded at the level of the ensiform process (VE), and the epigastric level midway between the latter and the umbilicus (V_sp). Esophageal leads were obtained in several of these cases. In the remainder of the cases only the 12 standard leads were analyzed (group E).

Results

Group A

This group consisted of electrocardiograms of 22 patients in which the U wave was positive in all the standard precordial leads and exceeded 0.1 mv. in at least 1 lead. There were no cases of myocardial infarction, pericarditis, bundle-branch block, or electrolyte imbalance. None of the patients was receiving digitalis or quinidine therapy.

Relation of U to QRS. There was no consistent relationship between the QRS and the U-wave amplitude in any of the cases studied. In 18 cases the tallest QRS and the tallest U wave were found in different leads. In 4 cases the tallest QRS and the tallest U wave were found in the same lead; in the remaining leads the U-wave amplitude did not bear a constant relationship to the QRS amplitude.

Lead with Tallest U Wave. The tallest U wave was distributed as follows: lead V_2E, 5 cases; V_3E, 3 cases; V_3', 3 cases; V_2, 3 cases; V_2', 2 cases; V_4, 2 cases; V_3, 2 cases; V_4, 1 case; and V_4E, 1 case.

Relation of U Wave to T Wave. In 20 cases the tallest U wave and the tallest T wave were in the same lead. In all leads of these 20 cases, the ratio of the amplitude of the T wave and the U wave remained constant (usually 3:1 to 4:1). In the 2 remaining cases the tallest T wave and the tallest U wave occurred in different leads and the ratio of the T wave and the U-wave amplitudes was not constant.

Group B

This group consisted of the electrocardiograms of 19 cases in which the U wave was negative and deeper than 0.1 mv. in at least 1 precordial lead. There were no cases of myocardial infarction or the other conditions mentioned under group A.

Distribution of Negative U Waves. The U wave was negative in leads V_5 and V_6 in all 19 cases; in V_6' in 9 cases; in V_6 and V_7 in 8 cases; in V_4 and V_4E in 6 cases; in V_4 and V_4E in 4...
cases; in V₃, V₅, V₆ and V₇ in 2 cases; and in V₁, V₂, V₃, V₅p, and V₆ in 1 case.

Lead with Deepest U Wave. The deepest negative U wave was found in lead V₅ in 11 cases, in V₆ in 6 cases, in V₇ in 1 case, and in V₄ in 1 case.

Relation of U Wave to T Wave. In 14 cases the polarity of the T wave and the polarity of the U wave were the same and the ratio of the T and U amplitude was constant. The transition between the positive and negative T wave and U wave also occurred in the same precordial leads (fig. 1). The electrocardiograms of all of these cases presented an electrocardiographic "left ventricular strain" pattern. In the remaining 5 cases a negative U wave was found in certain leads with a positive T wave.

Group C

This group consisted of electrocardiograms of 18 patients in which the QRS complexes were wider than 0.12 sec. Three patients showed left bundle-branch block, 3 right bundle-branch block, 10 ventricular premature beats, and 2 a slow idioventricular rhythm.

Relation of U Wave to T Wave. The same polarity of the U wave and the T wave and the constant ratio of the U wave and T wave amplitude were found in 16 cases (fig. 2). In 2 cases with premature ventricular beats in which the T wave was negative, the U wave was positive in certain leads.

The polarity of the U wave could be determined with certainty only in cases in which the duration of the QRS complex did not exceed 0.15 to 0.17 sec. In cases with wider QRS complexes the end of the T wave usually falls either at the apex or beyond the apex of the U wave, causing extensive merging of the T wave with the U wave. If the apex of the U wave is not clearly visible, the determination of the polarity of the U wave is not possible.

Group D

This group consisted of electrocardiograms of 19 patients with T-wave changes due to myocardial infarction or digitalis. In 12 of the 13 cases the pointed, inverted T wave was followed by a positive U wave. In 1 case the U wave was negative in the left precordial leads where the coved, inverted T wave of the infarction was also present. The follow-up
studies of the cases with infarction failed to reveal any changes in the shape or polarity of the U wave during a period of 2 to 8 weeks, although the usual evolution of the T wave took place.

In 6 cases where observations were made during digitalis therapy and in which the U wave exceeded 0.2 mv. in at least 1 lead, no changes in the polarity of the U wave were noted during the period of observation (fig. 3).

**Group E**

This group included the electrocardiograms of 376 hypertensive patients in whom the systolic blood pressure was above 170 mm. Hg or the diastolic pressure above 100 mm. Hg. The T and U waves were examined only in the precordial leads V1 through V6. This analysis was performed only in the cases where the U wave was clearly visible. In all doubtful cases, the following method of identification was applied. The longest Q-T interval in a lead with a monophasic T wave and the longest P-R interval in any of the leads were determined. Both of these intervals were plotted on a tracing of the lead in which the presence of a U wave was suspected. If the interval between the end of the T wave and the beginning of the P wave was less than 0.08 sec., the U wave polarity could not be definitely determined and the tracing was discarded (fig. 4). It became necessary, therefore, to reject almost all tracings.

**Fig. 2.** A. In left bundle-branch block, the U wave is positive in leads with a positive T wave and negative in leads with a negative T wave. B. In right bundle-branch block, the U wave is negative in leads V1 and V4 in which the T wave is also negative. C. In the normally conducted beats, a negative U wave follows a small, notched T wave. In the ventricular premature beat, both the U wave and the T wave are positive. D. In the normally conducted beats, both the U wave and the T wave are positive. In the ventricular premature beats, both the U wave and the T wave are negative. E. In the normally conducted beats, both the U wave and the T wave are negative. In the premature beat, both the U wave and the T wave are positive.
with a heart rate faster than 96 beats/min. In addition, several tracings with a slower heart rate were discarded for 1 of the following reasons: prolongation of the P-R interval, atrial flutter and supraventricular tachycardia with A-V heart block, coarse atrial fibrillation, bigeminal rhythm, conduction disturbances with a QRS duration exceeding 0.17 sec., marked Q-T interval prolongation, and technical errors. A total of 79 tracings was discarded. In the remaining tracings the tallest U wave was found most frequently in the lead with the tallest T wave. The distribution of the tallest positive U waves was as follows:

<table>
<thead>
<tr>
<th>Lead</th>
<th>Cases</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_2</td>
<td>115</td>
<td>46</td>
</tr>
<tr>
<td>V_1</td>
<td>63</td>
<td>25</td>
</tr>
<tr>
<td>V_3</td>
<td>62</td>
<td>25</td>
</tr>
<tr>
<td>V_2</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>V_1</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>251</td>
<td>100</td>
</tr>
</tbody>
</table>

The relation of the polarity of the T wave and the U wave is presented in figure 5. The cases were subdivided into 6 groups. The largest group includes normal and abnormal tracings with a positive T wave and a positive U wave in all the precordial leads. The second, third, and fourth groups include almost exclusively electrocardiographic patterns of “left ventricular strain” or left bundle-branch block and the difference between those groups are due solely to a different polarity of the U wave. The fifth

Fig. 3. Electrocardiogram of a 78-year-old white woman (A) before digitalis administration and (B and C) after digitalization. There is progressive inversion of the T wave in leads V_1 through V_6. The polarity of the U wave is unchanged.

Fig. 4. The U wave appears to be negative in lead V_1. But when the P-R interval, measured in lead V_1, and the Q-T interval, measured in lead V_6, are plotted on the tracing, the T-P interval measures only 0.08 sec. The determination of the shape and polarity of the U wave in this case is not possible.
group includes cases with a discordance of polarity of the T wave and the U wave in certain leads. There were 5 cases of myocardial infarction with pointed, inverted T waves followed by positive U waves; 7 cases with inverted T waves in leads V1 and V2 (juvenile pattern), followed by positive U waves; 1 case with an isolated inversion of the T wave in lead V4 (transitional T wave), followed by a positive U wave; 1 case of right ventricular hypertrophy pattern with an inverted T wave in leads V1 and V2 followed by a positive U wave; and finally 2 cases of “left ventricular strain” pattern in which both the T wave and the U wave were negative in leads V5 and V6, but in lead V4 the T wave was negative and the U wave was positive. It was considered that, with the exception of the last 3 cases, the T-wave inversion in this group was of primary origin. The sixth group included 7 cases with an inverted U wave in several precordial leads in which the T wave was positive. Six of these cases had several other abnormal electrocardiographic features besides the inverted U wave.

This study showed that less than one half of the cases in which the inversion of the T wave is presumably of secondary origin had an inverted U wave in leads with the inverted T wave. Inversion of the U wave without inversion of the T wave was a relatively rare finding in our group. The impression concerning a discordance between T wave and U-wave polarity in the presence of primary T-wave changes was confirmed.

Other Observations

Esophageal leads were taken in several cases in which the U wave exceeded 0.2 mv and was well separated from the T wave. The U wave was usually obscured by artifacts and could be identified with certainty in only 3 cases. The polarity of the U wave was the same as the
Fig. 6. A deep negative U wave in leads I and V3 through V6 in hypopotassemia decreases in amplitude after potassium administration. The polarity remains unchanged.

polarity of the T wave and the ratio of the T wave and the U wave amplitude was the same as in the precordial leads.

The increase of the U-wave amplitude in hypopotassemia has been observed in 2 cases in which the U wave was negative. As previously suspected, hypopotassemia does not change the polarity but affects only the amplitude of the U wave (fig. 6).

A change in the polarity of the U wave was observed in several cases following a change of heart rate. In some cases the faster heart rate was accompanied by a negative, and a slower rate by a positive U wave. In certain cases the

Fig. 7. Electrocardiogram of a 54-year-old Negro man with hypertension. A fall in blood pressure is accompanied by a change from a negative U wave in leads I and V6 to an isoelectric U wave in these leads. In lead V5, the change was from a negative U wave to a positive U wave.
heart rate was unchanged or even faster in the presence of positive U waves. In 3 cases of the latter type, the blood pressure was found to be higher in the presence of a negative U wave (fig. 7). In 1 case, repeated administration of nitroglycerin was associated with a change from an inverted to an isoelectric U wave accompanied by a drop in the blood pressure (fig. 8). In all of the described cases U wave changes were accompanied by at least some T-wave changes, and therefore it was impossible to decide whether or not the changes of the U-wave polarity were primary.

DISCUSSION

Variations in the interpretation of the U wave are due largely to difficulties in its identification. It has been stated that the U wave may be confused with an apparent terminal “dipping” of the T wave\(^2\) and with a depression of the T-U junction.\(^3\) Part of the P wave may also be mistaken for the U wave, making accurate determination of the P-R interval imperative.\(^4\) It has also been found that the U wave cannot be clearly delineated when the heart rate is more than 110/min.\(^4\) In our experience, clear demarcation of the U wave requires plotting both the Q-T and the P-R intervals. The application of this method leads us to the conclusion that in the majority of cases, the determination of the shape and polarity of the U wave is impossible when the heart rate is above 96/min. The similarity in the shape of the U wave and the T wave as well as the frequent occurrence of tall U waves in tracings with tall T waves has been noted previously.\(^4\) This similarity probably accounts for the fact that the U wave was once called “a dicrotic T wave.”\(^10\)

It has been reported that digitalis may influence the polarity of the U wave.\(^11\) This has not been observed in our experience.

We have found that in electrocardiograms of hypertensive patients, the majority of negative U waves accompany secondary T-wave inversion. But since in only about one half of the cases with presumably secondary T-wave inversion there was an accompanying U-wave inversion, it seemed to us that the inversion of the U wave might be a later event. Some of our observations of the evolution of the “left ventricular strain” pattern led us to believe that there is a gradual transition from a positive U wave to an isoelectric U wave to a negative U wave in the left precordial leads. A negative U wave in the presence of a positive T wave was rarely found. Such a finding may be due to either a primary inversion of the U wave or to a change in the polarity of the T wave from negative to positive in a case with a previously inverted U wave. The latter was observed during the development of a peaked, positive T wave after subendocardial infarction or acute coronary insufficiency. In some of the observed cases of left ventricular hypertrophy pattern, the U wave was negative in the left precordial leads while the T wave was still positive. All such cases were associated with
marked hypertension and in 2 cases this finding was present during exceptionally fulminating malignant hypertension. Negative U waves in the presence of positive T waves were almost always associated with other electrocardiographic abnormalities, particularly with low T waves. We have seen only 1 case in which a negative U wave accompanied a normal T wave. Only a few cases of this kind have been published\(^8\), \(^12\), \(^13\) and in 1 of them (fig. 1 of Twiss and Sokolow's article\(^{14}\)) the T wave became deeply inverted after exercise.

In all the observed cases in which a negative U wave became positive after slowing of the heart rate or a drop in blood pressure there were some concomitant T-wave changes. This was also observed in cases in which a negative U wave became positive after sympathectomy (figs. 8 and 12 of the article by White and co-workers\(^{15}\)).

**Summary**

The ratio of the amplitude of the QRS complex to the amplitude of the U wave varies in different leads of the same electrocardiogram. In the majority of electrocardiograms, the U wave has the same polarity as the T wave and the ratio of the U wave and T wave amplitude is relatively constant in all leads. The tallest positive U wave is usually observed in the area of leads V\(_2\) to V\(_4\). The deepest negative U wave is usually observed in the area of leads V\(_4\) to V\(_6\). Secondary changes of the T wave are very frequently accompanied by similar changes of the U wave. T-wave changes caused by myocardial infarction and digitalis are usually not accompanied by changes of the polarity of the U wave.

The electrocardiograms of 297 cases of hypertension were divided into 6 groups on the basis of the relationship between the polarity of the T wave and the U wave. Both waves were positive in all precordial leads in 48.1 per cent of the cases. Negative U waves were found in 21.8 per cent of the cases and these were predominantly in the leads with negative T waves. A negative T wave in the left precordial leads was accompanied most frequently by a negative, less frequently by an isoelectric, and least frequently by a positive, U wave. An inverted U wave in the presence of an upright T wave was found in only 2.8 per cent of the cases. A change from a negative to a positive or isoelectric U wave was observed after slowing of the heart rate, a drop in blood pressure, and nitroglycerin administration.

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